AXIAL REVERSED COOLING OF A ROTOR AND A COIL END SECTION IN AN ELECTRICAL ROTATING MACHINE

Technical field

The present invention relates to rotating electric machines such as synchronous machines, normal asynchronous machines as well as duel-fed machines, applications in asynchronous static current converter cascades, outerpole machines and synchronous flow machines as well as alternating current machines intended in the first place as generators in a power station for generating electric power. The invention relates particularly to the cooling of rotors in turbo applications of such machines having an axial airflow through the axial ducts of the rotor thereby cooling the insulated electric conductors that constitute the rotor winding and indirectly also the rotor poles.

Background art

The invention is based on systems, in which the stator cooling circuit is separated from the rotor cooling circuit, such as when the stator is water-cooled. The air must have a certain velocity and a certain volume flow in the ducts so as to obtain sufficient cooling of the rotor and the field winding inclusively, in order to air-cool the rotor in an electric machine in which the rotor is provided with air ducts. It is hereby desirable to achieve sufficient air speed (m/s) as well as sufficient air volume (m^3/s) in the ducts of the rotor with the least possible ventilation losses. The ventilation losses arise partly as a result of air gap friction and partly as a result of a component, which is proportional to the total air volume blown into the ducts of the rotor. The flow volume should therefore be as small as possible in order to minimise the ventilation losses.

In the case of combined air cooling of both the stator and the rotor it is usually the permissible rise in the air temperature that determines the airflow. Not much can be done about solving the problem of minimising ventilation losses since the rise in temperature is only dependent on the total power losses and the airflow; the airflow being unequivocally determined by losses and permissible rise in temperature.

The airflow may be minimised if the stator is water-cooled instead because the air does not need to transport as much heat effect away from the generator.

Besides, when only the rotor is air-cooled, it is the coefficient of heat transfer at the field windings, which is dimensioned, and not the rise in temperature. The coefficient of heat transfer rises when the air speed rises. Thus, by forcing the air to pass close to the field windings the necessary airflow required can be reduced.

Furthermore, cooling of the coil end parts, located axially at both ends of the stator, is required. One of the main problems for cooling this section, after the airflow has passed the rotor, is that the coil end section tends to be unsatisfactorily cooled.

In conventional cooling systems both cooling of the rotor and cooling of the stator is almost always combined so that the air also passes the radial cooling ducts of the stator after having passed the rotor. This can give rise to high air temperatures where the air from the rotor comes into contact with the stator. This is partly dependent on air from the rotor absorbing heat losses in the rotor and the field winding inclusively, and partly dependent on the whole rotational effect of the air being transformed into heat in the rotor and the air gap.

Similar machines have conventionally been designed for voltages in the range 15 - 30 kV whereby 30 kV has normally been considered to be an upper limit. In the case of generators this means that a generator must be connected to the power network via a transformer which steps up the voltage to the level of the power network which lies in the range of approximately 130 - 400 kV. The present invention is intended for use with high voltages. High voltages shall be understood here to mean electric voltages in excess of 10 kV. A typical operating range for a rotating electric machine comprising an air-cooled rotor, according to the invention, may be voltages from 36 kV up to 800 kV.

By using high-voltage insulated electric conductors in the stator of the machine, i. e, high-voltage cables, having permanent insulation of similar design to that used in cables for transmitting electric power (e.g. so-called PEX cables), the voltage of the machine can be increased to such levels that it can be connected directly to the power network without an intermediate transformer. The conventional transformer can thus be eliminated. The high-voltage cable comprises a number of strands having a circular cross section, which is made of copper (Cu). These strands are arranged in the centre of the high-voltage cable. Around the strands there is arranged a first semiconducting layer. Around the first semiconducting layer there is arranged an insulation layer, e.g. PEX-insulation. Around the insula-

tion layer there is arranged a second semiconducting layer. Reference made to high-voltage cable in the present application does thus not comprise the outer shielding means and the metal screen that normally surrounds such a cable in the distribution of energy.

Technology with one-way axial cooling in which the stator is not included in the cooling circuit is known in applications for smaller machines showing open pole gaps. Axial cooling through pole gaps, which are covered, are also known, see PCT WO98/20600.

These known types of air-cooling and water-cooling provide partially unsatisfactory cooling of especially the coil end section of a machine of the present type resulting in high ventilation losses.

Aim of the invention

The aim of the invention is to provide a method and a device for controlling the airflow in axial cooling of the rotor in order to primarily protect the cables of the stator from warm air in a rotating electric machine, especially of the type where the stator windings of the machine constitute said high voltage cables. An additional aim of the invention is to cool the coil end section with the same cooling means that cools the rotor thereby first cooling the coil end section in such a machine. The aim of the invention is to also avoid warm air from coming into contact with the stator. A further aim is to achieve a higher efficiency by reducing the ventilation losses in an air-cooled rotor. Indication of further advantageous developments of the invention follows in the description below.

Summary of the invention

The aim of the invention is fulfilled by the invention pertaining to the characteristic features given in the appended claims. The invention is based on a machine with an air-cooled rotor and water-cooled stator where the coil ends of the stator are firstly cooled through the circulation of cooling air through the coil end section and then cooled through the air gap between the stator and the rotor. Cooling first the coil end section with cooling air and thereafter the rotor implies that the most sensitive parts, which do not tolerate high temperatures, are cooled first. This is achieved by cooling air passing the coil end section first and then being led into the air gap between the stator and the rotor so that the cooling air re-

verses at the centre of the rotor, due to meeting a cooling airflow from the other side of the rotor, so as to then return through the rotor ducts within a closed cooling circuit. The reversal of the cooling airflow takes place gradually axially along the rotor so that it is completely reversed at the centre of the rotor. There are rotor fans at the centre of the rotor in order to simplify the reversal of the airflow, which rotor fans, seen from a radial section, are bevelled. The reversal of cooling air takes place gradually automatically because the cooling is completely symmetrical when the flow between the stator and the rotor from the one side of the rotor meets the flow from the other side of the rotor.

The present invention is especially suitable for a rotating electric machine having stator winding composed of high voltage cable, which with today's technique requires a temperature of 70°C.

Fundamental to the invention is that the temperature sensitive parts of the generator must be firstly cooled by cool air or other gasses. The invention is also based on the turbo generator where both the stator coil ends and the rotor are cooled by air or other gasses. The invention may also be applied solely to cooling of the rotor and applied with certain modification to hydro-generators. Air-cooling takes place in the following order: the air cooler, the stator coil ends, the air gap and lastly the rotor. The invention is especially applicable to stator winding consisting of cables having a relatively low permissible operating temperature.

From a cooling point of view, the optimal direction of the cooling airflow is reversed when compared to the conventional direction of the airflow in the cooling ducts of the rotor i.e., directed from the periphery of the rotor towards the centre of rotation. A larger driving pressure is required for this solution when compared to a conventional cooling method. The driving pressure is obtained from the one fan in combination with the one diffuser. The diffuser converts the greater part of the dynamic pressure of the air to static pressure, at the air outlet of the rotating part of the generator. This is a great advantage when compared to a conventional cooling method where the whole rotational effect of the air is transformed to heat in those sections of the generator, which are to be cooled. The reversed direction of the flow in the rotor produces higher ventilation losses of air per unit of volume compared to the conventional cooling method as a result of the necessary power produced by the fans. This depends on the ventilation losses of air per unit of volume, derived from passing through the ducts of the rotor, being partly proportional to the

speed of rotation of the air and partly proportional to the speed of rotation of the rotor or alternatively the speed of rotation of the fan at the outlet from the rotating parts of the generator. A higher periphery speed of the fans is required than of the speed of the rotor in the air gap in order to drive the air into the reverse direction through the rotor. The total ventilation losses are low despite this.

Minimisation of the volume flow is partly obtained by the temperature sensitive parts being cooled first and partly by the rotational effect of the air being converted to a driving pressure and heat after the air has left those parts which are to be cooled. The losses due to air gap friction are small because the rotational effect of the air in the air gap results in additional power at the inlet for air to the rotor instead of getting lost in heat. The ventilation losses for this ventilation principle may be further minimised by producing a smooth surface of the stator in the air gap of the stator.

There are also demands for maximum temperature on the rotor retaining ring, which keeps the rotor winding in place and which shrinks firmly to the rotor during the manufacturing process. The ventilation principle, according to the invention, surrounds the whole rotor-retaining ring with cold air. This implies both the surface of the rotor retaining ring towards the air gap and the surface towards the centre of the rotor. The warm air from the rotor is prevented from coming in contact with the rotor-retaining ring. The cold airflow from the coil end section to the rotor end also cools the rotor-retaining ring effectively.

Brief description of the drawings

The invention will now be described in more detail with reference to the accompanying drawings in which one symmetrical part of the generator is shown:

Figure 1 shows one schematic axial view of a rotating electric machine, partially in section, with an air-cooled rotor in accordance with the present invention.

Figure 2 shows a partial cross-sectional radial section A-A through the rotor according to Figure 1.

Figure 3 shows an enlarged partial view having a superposed radial section B-B according to Figure 1.

Description of the invention

Figure 1 shows a rotating electric machine 1 comprising a stator 2 with a stator winding 3, in the form of high voltage cable. The machine 1 is provided with a rotor 4, which is arranged on a machine shaft 6 that is journalled in a machine housing 5. An air gap 15 is formed between the stator 2 and the rotor 4. The rotor 4 is also provided with a radial fan 8 having blades 7, which fan increases the pressure on the cooling airflow reversing into a diffuser 18. The dynamic pressure of the airflow in the diffuser flow is converted to approx. 60 % static pressure, whereby the remaining pressure forms heat. Approximately half of the increase in pressure takes place in the fan and the remaining increase in pressure takes place in the diffuser. The airflow passes the air cooler 19 and holes, located between the cooler and the coil end section, before entering the coil end section 20. The embodiment also shows, in accordance with Figure 1, that the total airflow through the cooler 19 is 1,7 m^3/s of which 0,5 m^3/s (30%) cools the rotor end 21, directly after the coil end section 20, and of which1,2 m^3/s (70%) flows into the air gap 15 between the stator 2 and the rotor 4. The airflow through the coil end section 20 rotates due to the outlet holes being angled such that eddy formations and turbulence are achieved. The air is alternatively guided through the coil end section with the aid of screens 16, 17.

The cooling airflow from both ends of the rotor, which is indicated by arrows in Figure 1, meets in the air gap 15, since the cooling arrangement is symmetrical. Both these cooling airflows tend to depart in the radial direction from where they meet, i.e. towards the centre of the rotor. The rotor wedges at the radial inlet for the air in a radial rotor duct 11 have been bevelled to simplify the change of direction. Figure 2 shows how such a bevelled rotor wedge 12 may be arranged where an arrow indicates how the airflow deflects radially. The airflow is deflected outwardly from the rotor 4 back into a reversed axial flow via axial rotor ducts 9. Figure 1 shows the distribution of the airflows indicated by arrows. The cooling is symmetrical around the centre line. This means cooling of the rotor in two-way axial ducts. It is hereby also evident how the coil end parts 20 allow for cooling by the airflow, before cooling of the rotor with its windings.

Figure 2 shows a partial radial section through the rotor 4, which is designed with rotor ducts 9 at both sides of each field winding 10. A rotor wedge 12 is arranged at the tops side of each field winding 10. The rotor wedge 12 is pro-

vided with a bevelled outer edge 13 to simplify the process of the airflow being deflected radially into the radial rotor ducts 11. Each radial duct 11, excluding those located beside the poles, provide two axial ducts 9 with air. In smaller entirely air-cooled machines the air gap is used to blow air through for cooling purposes in both the stator and the rotor. This is an uneconomical cooling method for larger machines, as in the present case of a water-cooled stator, and this type of air stream through the air gap should therefore be as small as possible so that it may be used where it is better needed such as in the present case for air flowing through the rotor ducts and for simultaneous cooling of the coil end parts.

Figure 3 shows by means of arrows in an axial section the reversing cooling-airflow on its way back from the rotor through the rotor ducts 9 while cooling the rotor windings at the same time. Both cooling airflows are united at the rotor end 21 once more whereby the flows are forced further through a ring-shaped duct 23. The duct 23 is formed by attaching a coaxial pipe onto a rotating rotor axial 27 via radial means of attachment 29, which are shown in a radial section in Figure 3. The circulation of cooling air is achieved by the blades 7 of the fan 8 located at the end of the pipe 25 and the fan that is attached to the rotor axial. The fan forces the cooling air further through the diffuser 18 and still further through the air cooler 19 circulating continually. Thus, the air temperature rises during the conversion of pressure in the diffuser, as described in the introduction, and then sinks back again in the air cooler. The diameter of the radial fan 8 is larger the diameter of the rotor.

The stator winding 3 of the machine is composed of a high voltage cable in the form of a flexible electric conductor having a casing capable of trapping the electric field accrued around the conductor. The casing also comprises an insulation system with an insulation made of a solid insulation material and an outer layer on the outside of the insulation having an electric conductivity higher than the insulation so that the outer layer, by being connected to earth or otherwise relatively low potential, is capable of partly functioning in a potentially equalising way and partly in principle, containing the accrued electric field on the inside of the outer layer as a result of said electric conductor. The insulation system comprises an insulation, made of a solid insulation material, and an inner layer on the inside of the insulation, at least one of the said electric conductors being arranged on the inside of the inner layer, and that the inner layer has a lower electric conductivity

than the electric conductor but sufficient for the inner layer to function in a potentially equalising way and thereby equalising with respect to the electric field on the outside of the inner layer. The solid insulation and the outer layer are made of polymer material.